Power Production in the Next Century

Evolution of PC Combustion Technology

Workshop Proceedings

June 15-16, 1999 • Arlington, Virginia

Points of Contact:

Arun C. Bose (bose@netl.doe.gov). Phone: (412) 386-4467

Sean I. Plasynski (plasynsk@netl.doe.gov). Phone (412) 386-4867

A majority of power plants in the U.S. use pulverized coal (PC) as fuel. This document describes the results of a Workshop where industry professionals discussed the future of pulverized coal technology, especially its evolution as a competitive power production choice in the early decades of the next century. The United States Department of Energy's (DOE) Federal Energy Technology Center (FETC) organized and hosted this Workshop, titled: "**Power Production in the Next Century - Evolution of PC Combustion Technology**." FETC held this Workshop in Arlington, Virginia on Tuesday June 15th and Wednesday June 16th, 1999.

The Workshop was part of a larger FETC effort that aims at soliciting industry stakeholder inputs in FETC's advanced power systems development program planning process. Industry input is important. It helps establish government-industry research, development, and demonstration (RD&D) partnerships that develop energy technology for the U.S. and the world. Specific objectives of the June Workshop included:

- Identify near-, mid-, and long-term issues of concern to electric power and coal producers. These addressed the effects expected from existing environmental regulations, and the effects which might be expected from more stringent environmental regulation limits that might be established in the future.
- Identify the cost and performance of the existing electric power generation fleet that presently competes in an increasingly deregulated market. This gives a benchmark of performance and cost that new technologies must achieve if they are to succeed.
- Identify industry's perception of the desired evolution in the technology development path of pulverized coal electric generation plants that will be needed in the early decades of the next century.
- Establish appropriate levels of reduced capital and operation costs, better environmental performance, and increased energy efficiency needed from these new plants, for them to be attractive to the power industry. If DOE's new technology products are to compete successfully and displace present technology choices, then, the new technology must improve the prospects for profitable operations to a generating unit owner.

The Workshop identified many of the characteristics that industry expects from new electric power generation technologies.

The Workshop also met a collateral objective: it provided a forum where industry stakeholders could interact and participate in addressing and building consensus on pulverized coal generation research topics. It allowed the group to establish technology development priorities. The workshop identified the need for 21st century units that will operate more profitably for the owners, that will reduce wasted energy, and that will provide our nation and the world with generation units with exemplary environmental cleanliness.

The output from the Workshop is a technology roadmap. The roadmap is helping to define DOE's out-year plan for executing promising technology approaches. The roadmap identifies research and development needs and establishes the timing needed for future government-industry research and development partnerships.

Speakers at the Workshop gave a wide variety of papers on diverse aspects of pulverized coal technology. These addressed issues on cost, efficiency, environment, global warming, and the materials needed to construct plants. FETC Director, Ms. Rita A. Bajura set the stage by giving a talk on “Global Climate Change Implications for Fossil Fuels.” Ms. Connie Holmes, Senior Vice President of the National Mining Association, gave a keynote talk on the “Mining Industry Perspective on Future Coal Utilization.” Mr. William Sullivan, Vice President of the Pacific Gas and Electric Generating Company, set the tone for the afternoon theme by giving a talk on the “Effects of Deregulation on Power Plant Efficiency and Costs.”

In addition to the prepared talks, the Workshop provided several break-out sessions. Three break-out sessions provided a forum to openly discuss the following topics:

- Environmental issues facing coal and power producers.
- Existing fleet of pulverized coal plants - keeping the cost and environmental performance competitive with other alternatives.
- The future of new pulverized coal plants in the U.S. and abroad - technology concepts with reduced capital and operating costs, superior environmental performance, and increased efficiency.

The break-out sessions provided the stakeholders open forums to address the issues facing the coal and power industry, to build consensus on research topics and technology priorities for the continued, successful evolution of advanced pulverized coal technology in the next century.

Contents

Introduction

This is a summary of electric power industry comments from discussions at a DOE-sponsored Workshop, the "Power Production in the Next Century–Evolution of PC Combustion Technology," Workshop held on June 15-16, 1999 in Arlington, Virginia. The Workshop focused on the evolution of pulverized coal combustion (PCC) technology in the next century.

This summary reports comments from attendees from generating companies, utility vendors, manufacturers, power industry consultants, universities, and from the government. These came from two "Break-Out" groups, Group I and Group II, that consisted of a number of industry stakeholders. These Break-Out groups allowed facilitated discussions of a number of issues important to FETC. Group I and Group II met in three separate sessions each. Notes from these sessions are reported here. Each group approached the same list of questions, but each had its own unique vision and perspective on how to address the several issues under discussion. Group I and Group II met at the following break-out sessions, with notes from the following people:

	Tuesday, June 15, 1999 morning	**Tuesday, June 15, 1999 afternoon**	**Wednesday June 16, 1999**
Group I Facilitator:Edward Skolnik Session Scribe: Sean Plasynski Master Scribe: Richard Weinstein	Break-Out 1A	Break-Out 1C	Break-Out 1E
Group II Facilitator: Joseph S. Badin Session Scribe: Harvey Goldstein Master Scribe: Richard Weinstein	Break-Out 2B	Break-Out 2D	Break-Out 2F

Appendix material gives a complete set of discussion notes from each of these six break-out sessions for the two groups. These notes from the Session Scribes are the basis of this Summary.

Workshop Agenda

The agenda for the two-day workshop was as follows:

Tuesday, June 15, 1999

Morning Theme: Issues facing coal and power producers

08:00 AM	Introductory Remarks: Welcome, Purpose: Don Bonk, FETC
08:15 AM	Global Climate Change Implications for Fossil Fuels: Rita Bajura, FETC
08:45 AM	A Mining Industry Perspective on Future Coal Utilization: Connie Holmes, NMA
09:20 AM	PC Power Generation Fleet: Future Technology Needs: Joe Darguzas, Sargent & Lundy
09:50 AM	Evolving Environmental Regulations, Issues and Concerns: Tom Burnett, TVA
10:20 AM	Guidance for Breakout Discussion Groups: Harvey Ness, FETC
10:30 AM	Break
10:45 AM	Facilitated Group Discussion: Identification of Major Environmental Issues *What are the major environmental issues for the near-, mid- and long-term? Prioritize. How can environmental performance be improved? What kind of technology? When needed?*
12:15 PM	Lunch

Afternoon Theme: The Existing Fleet of PC Plants -- keeping the cost and environmental performance competitive with other alternatives

1:30 PM	Panel Session on Theme — Moderator: Joseph Strakey, FETC
	Effects of Deregulation on Power Plant Efficiency and Costs: William Sullivan, US Generating Co.
	Retrofit Approaches to Reducing Operational Costs and Emissions: Harvey Goldstein, Parsons
	Repower with FW=s High Performance Power System: Mark Torpey, Foster Wheeler
	Oxygen Enriched and Flue Gas Recycle Combustion: Richard Doctor, ANL
3:15 PM	Break

3:30 PM Facilitated Group Discussion: Definition of Cost and Environmental Performance Goals for Existing Fleet

How can PC technology stay cost competitive?

What modifications to the existing fleet can help address future cost and environmental performance issues?

What are the scenarios that make repowering, retrofitting, and life extension attractive?

What are the roles for industry and government in seeing that the technology needs are met? What R&D partnership roles can be identified?

5:30 PM Social Hour

Wednesday, June 16, 1999

8:00 AM Welcome and summary of previous day=s facilitated discussion: Don Bonk

Session Theme: A future for new PC plants in the U.S. and abroad B Mid-term technology concepts with reduced capital and operation costs, superior environmental performance, and increased efficiency

8:15 AM Panel Session on Theme Moderator: Lawrence Ruth, FETC

Advanced PC Power Plants Technologies: Mike DeLallo, Parsons Company

Low Emission Boiler System: Rod Beittel, DB Riley

UTRC=s Greenfield High Performance System: Dan Seery, United Technologies Research Corp.

Efficiency Enhancements for Supercritical PC Plants: Dennis McDonald, Babcock & Wilcox

Advanced Materials for PC-Power Plants: Peter Tortorelli, ORNL

10:15 AM Break

10:30 AM Facilitated Group Discussion: Opportunities for New PC Plants

What are the opportunities and issues for new PC plants in the U.S. and in developing countries? - Near-, mid- and long-term.

What improvements in systems, equipment and materials are required to overcome barrier issues?

What R&D partnership roles can be identified?

12:00 PM	Summary of facilitated discussions: Harvey Ness, FETC
12:20 PM	Closing comments, output, products: Don Bonk, FETC
12:30 PM	Adjourn

Summary of the Workshop Break-Out Sessions

The break-out sessions for the Conference were facilitated discussions. Scribes recorded session notes. The general format for each session followed this approximate order:

- Brainstorm the major issues, analyze the issues, and group into major segments, and prioritize each issue for importance and relevance
- Brainstorm and prioritize technology solutions and prioritize goals for each solution
- Brainstorm and prioritize roles and partnerships between the government, institutions, universities, and industry
- Brainstorm and prioritize barriers to introduction of new solutions
- Brainstorm and prioritize research and development (R&D) needs

Highest Priority Activities Suggested by the Attendees

In many cases, the industry attendees were given the opportunity to prioritize goals and issues (see Appendix I). The list below gives those issues with the highest interest levels indicated by the attendees. These are the top 1/3 of the 155 issues that the attendees prioritized from among the several hundreds of issues on which they expressed opinions (Appendices A-F). The more "stars" (*****) in this list, the greater the number of attendees felt this was a key issue. Priority was assigned by industry, and the summary here only includes those with four or more "stars."

DOE did not participate in assigning priority to any issue.

Crosscutting R&D Activities Needed to Overcome Barriers

21*********************

Full characterization of fuel - i.e. arsenic is a catalyst poison, need to know if coal has this component; mercury removal technology development; blended fuels, biomass, and the utilization of blended fuels with biomass

8********..................Efficiency Improvement- near - term

7*******....................Cost / Economics- near - term

5*****........................Systems Integration- near - term

Pilot- and Commercial-Scale Demonstrations

11***********..........Develop/demonstrate high efficiency cycles - partnership

9*********................Develop technologies that provide a 20 percent energy efficiency improvement upgrade to existing plants

6******......................Provide commercial, full-size demonstrations

Government Regulations and Political Issues

7*******....................A rigorous, independent human health study on the impacts of the various compounds identified as pollutants or potential pollutants should be completed within 5 years. The goals for environmental regulations should be based on human health risk, not on measuring ability. (This impacts the future for both existing units and new units)

7*******....................Better Study of Human Health Impacts

6******......................The public needs to be provided with realistic messages on climate change

5*****........................Coordination of Regulation – near - term to 2006

Computer Modeling

6******......................Modeling and verification of new technologies (prior to demonstration)

5*****........................Existing Fleet: Industry-developed environmental impact evaluation and analysis - near - term to 2006

4****..........................Dynamic modeling of complex cycles

High Temperature Materials / Corrosion-Resistant Materials

13*************......Advanced material development for 1600 ºF steam (corrosion resistance)

5*****........................Stronger corrosion resistant materials for advanced steam cycles - government labs/industry (in-situ)

5*****........................Materials development for 2000 ºF

Major Environmental Issues, Technical Solutions

6******......................What is cost effectiveness for retrofit as the choice for environmental emission intensity (tons/kW) improvement – near - term to 2006?

5*****........................Full life-cycle analysis of environmental solutions – mid - term to 2010

Greenhouse Gases and Climate Change

7*******....................Demonstrate CO_2 capture system by 2005

7*******....................Greenhouse Gas issues – mid - term to 2010

7*******....................Commercialize lower cost oxygen separation systems - near - term

6******......................Membrane oxygen/air separation technology

6******......................CO_2 , CO_2 to energy efficiency relationship, and greenhouse gases – near - term to 2006

6******......................Develop technologies supporting the increased use of biomass (for both existing and new units) at 10-20 percent loadings with coal

6******......................CO_2 Emission issues – mid- to long-term

5*****........................Demonstrate CO_2 sequestration system by 2005
4****..........................Greenhouse Gas – long-term to 2015 and beyond
4****..........................Fundamental research on CO_2 sequestration

NOx Issues

11***********..........NOx-coupled with the issue that ammonia is not a good thing; would like to have in power plants/meeting NOx reductions without SCRs – near-term to 2006
7*******....................Develop low-temperature (about 300ºF) SCR catalyst to remove 90 percent of NOx by year 2003
6******......................Remove 95 percent of NOx from combustion turbines by year 2003
5*****........................Develop materials/designs that allow 5-year life for waterwalls under low NOx burner conditions
5*****........................continued topping combustor testing - near - term
5*****........................NOx reduction-make more cost effective – near - term to 2006
5*****........................SCR without ammonia – near-term to 2006
4****..........................NOx issues - near- to mid-term
4****..........................Integrated NOx control system demonstration - government/industry partnership - 2003
4****..........................Existing Fleet: Dry injection system needed - near - term to 2006

PM2.5 and Particulate Matter

6******......................Mercury issues – the challenge of trying to find something that is affordable for mercury control – near - term to 2006
6******......................Regional haze (3***) vs. particulates (3***)- near - term
5*****........................PM2.5 issues – mid-term to 2010
5*****........................Continued testing of high temperature (1600ºF) particulate filter

Mercury, Hazardous Air Pollutants (HAPs), and Toxic Release Inventory

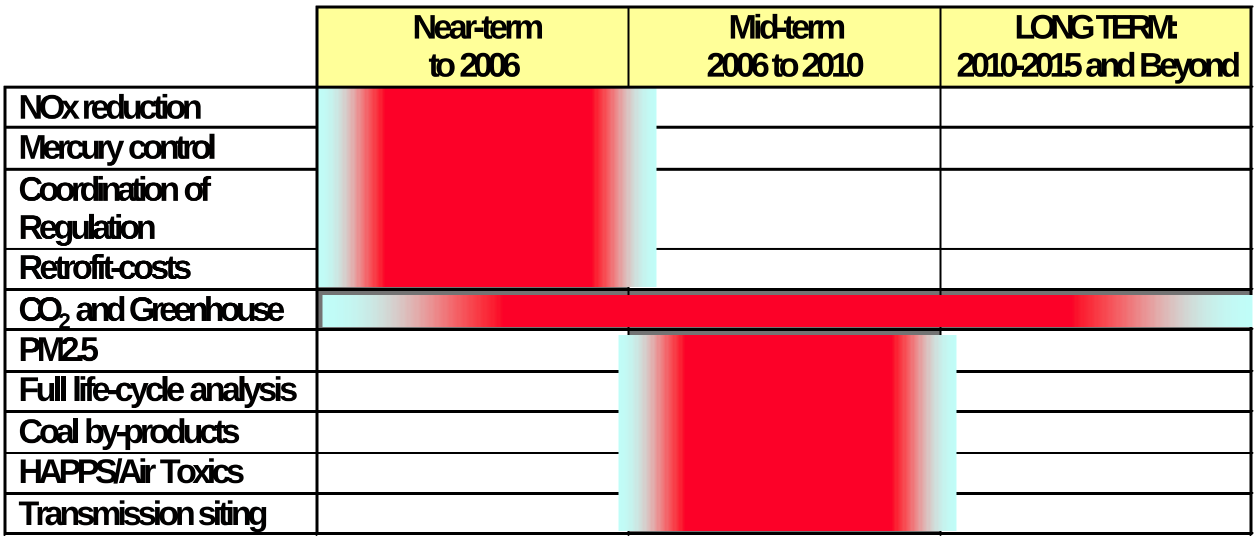
5*****........................Regulatory Practical Limit toxic release inventory (TRI) needs - near-term to 2006
4****..........................Mercury issues (cost of control) - near-term to 2006
4****..........................Existing Fleet: Mercury scrubbing needed - near-term to 2006
4****..........................New Pulverized Coal Plants: Mercury scrubbing needed - near-term to 2006

There Are Gems Amongst the Lower Priority Too. The higher priority issues above indicate higher industry interest. These rankings emphasize study areas of current broad-based industry need. These rankings suggest R&D areas that might need DOE emphasis. Some lower-ranked issues, not listed above, are also worth pursuing. The reader is encouraged to review the Appendices for the lower scored suggestions.

What are the Major Environmental Issues and Barriers?

Exhibit 1 gives a summary of the time periods when the attendees felt various environmental issues are most relevant.

Exhibit 1. Time Scale of Concern over Major Issues



The summaries that follow describe those felt the most important by the attendees.

Fuel Characterization

The highest evaluation priority consensus given in the entire meeting was the need for the full characterization of coal, so that birth-to-death environmental assessment had meaning. Cited, as an example was the lack of information on arsenic, a catalyst poison. The attendees felt they need to know if coal has these components. They need information on mercury, for mercury removal technology development. A particular need was to better understand blended fuels that incorporated substantial fractions of biomass, and the combustion and utilization of blended fuels with biomass fractions.

Increased Use of Biomass

There were a number of discussions about understanding the combustion characteristics and ash disposal characteristics of coal units fed with a substantial fraction of biomass. The attendees felt there is inadequate understanding of the characteristics and firing consequences of using substantial quantities of biomass fuels.

Some of the attendees noted that there is need for pulverizer/classifier development and testing for firing mixed fuels.

NOx Issues

- NOx issues were the most discussed and highest priority issues
- Many of the solutions are near-term, some move into mid-term
- Chemical sorbents for NOx, low NOx burners, combustion modifications, and fuel blending /co-firing, gas and coal reburn are proven ways to reduce NOx
- Today's capability for coal-fired boilers range from about 0.12 lb/10^6 Btu to mid 0.05 lb/10^6 Btu
- Low cost NOx reduction solutions for retrofit and new application are a high priority. Long-term, the NOx emission levels from coal need to be the same as natural gas, single digit (ppm) NOx (a target of around 0.10 lb/10^6 Btu), at a cost of no more than about $100/kW.
- Extending life of water walls to 5 years in units employing low NOx combustion is needed
- NOx detriments to visibility are not well understood

NOx – Selective Catalytic Reduction (SCR) (short - term) Technological Solutions and Needs

- Develop low temperature SCR and SCR catalyst (less than 300°F) to take out 90% of NOx by 2003
- What is the real performance of SCR and SCR catalysts with U.S. coals?
- Collateral damage from using SCR should be assessed
- Data base on the cost/availability of SCR equipment would be valuable

NOx - Without SCR (mid - term) Technological Solutions, Needs

- Coal reburn
- Are there alternatives to using ammonia in SCR? SCR without ammonia would be desirable
- Ozone injection or O_2 for NOx control promises emissions as low as natural gas
- Dry injection systems
- Improve low NOx burners
- Optimize burners - smart control might prove valuable
- Alternative reductant gases or sorbents needed. A suggested goal would be to develop a low-cost chemical sorbent to remove 95% of NOx from combustion turbine exhaust by 2003

CO_2 and Global Climate Change Issues

- Global climate change, CO_2 and other greenhouse gas issues were the next most discussed topics in the sessions
- There are significant differences in opinion on priority: high for some, for others medium to low
- Actions viewed as needed for each of the time frames: near - term, mid - term, and long - term. Actions needed to address CO_2 and global climate
- At issue with greenhouse gases – reduce them, and/or capture and sequester them

Climate Change Solutions and Actions

- There is a need for improved basic science, and understanding of greenhouse gas, and linkages to climate change
- CO_2 capture and sequestration can be considered, but it is important that impacts from CO_2 sequestration- ocean, land (EOR), etc.-all options, be understood
- Capture and sequestration of other greenhouse gasses was also discussed
- Develop technologies with low net CO_2 emissions:
  - High energy efficiency
  - Combined heat and power to increase total energy use efficiency
  - Ultra-supercritical cycle
  - Advanced Cycles (binary systems) separation is mentioned, but not a high priority choice
- There was a high level of interest in demonstrating a CO_2 capture and sequestration system by year 2005
- One of the near - term technologies viewed favorably was the suggestion for a CO_2 sequestration demonstration using a LANL-based idea for CO_2 mineralogical absorption in serpentine rock as the collection medium

Plant Upgrade Actions to Reduce Greenhouse Gas

- CO_2 recycle with O_2 combustion might be considered for the existing fleet
- Co-firing with biomass
- High-efficiency repowering
- Natural gas reburning

Mercury and Hazardous Air Pollutants (HAPs)

- Mercury scrubbing may be needed for existing and new units
- The challenge is cost: trying to find a method that is affordable
- Controlling HAPs, air toxics, heavy metals is viewed as a mid-term concern
- There is a need for better science on the health affects, and identification of sources causing these affects

Mercury Issues Solutions, Needs

- Mercury scrubbing – suggested target is for a 70 % reduction at a cost below about $20,000/lb mercury, to be achieved mid-term EPA was cited as having goals of 1.0 – 2.0 mills/kWh for 50% reduction
- Dry injection systems preferred

PM2.5 Particulate Matter

- Viewed as a mid-term high-priority concern
- There is a need for better science on the health affects, and identification of sources causing these affects
- Develop advanced baghouse materials, or use high temperature / high efficiency filters
- Increased SO_2 scrubber efficiency – PM2.5 as sulfur, then $150/kW at 95% sulfur removal is a suggested goal

Waste Products

While the attendees thought that considerations about power plant waste products was an important issue, their discussions and prioritization of issues did not reflect that. There are concerns for understanding waste ash characteristics, the use of solid wastes as saleable byproducts, and land use and disposal of ash and other solid wastes.

What Kinds of Crosscutting Technology Are Needed?

Crosscutting Issues

There was a considerable interest in developing new fossil generation technologies to full scale demonstration that would provide a 20 percent energy efficiency improvement per kilowatt, either as a repowering upgrade, or as a new plant. The goal is that fuel used for each kilowatt is reduced by 20 percent, equivalent to improving (reducing) the Btu/kWh heat rate by 20 percent about the same as an energy efficiency increase of about 7 percentage points.

- Efficiency improvement was a high priority
  - Advanced technology / cycles
  - Use of supercritical steam cycles
- Improved cost / economics
- Better systems integration
- Better materials / high-temperature materials
- More demonstrations at adequate scale
- Better Modeling
- There was a call to demonstrate high efficiency cycles as a government/industry partnership
- There was interest in testing new high efficiency advanced technologies fired with coal (HIPPS, SOFC, etc.)
- The reliability/accuracy of continuous emission monitoring systems (CEMS) needs improvement
- Better oxygen separation systems are needed for the production of low cost oxygen for such goals as improving NOx emissions, developing certain advanced technology power systems, and separating and sequestration of CO_2. Membrane technology air separation development had a high consensus as being a technology worth developing

Pilot and Commercial Scale Demonstration

The attendees were consistent in suggesting that full scale, or near full scale demonstrations are critical for the commercial introduction of new technologies. Demonstration needs to be at no less than ½ the scale of commercial size for some items, and full-scale for modules that may be used in multiples for a full sized system. The size of the test needed depends on the item tested. The demonstrations must be of a size needed that proves lowered risk to investors.

Features Expected in New PC Plants – Near-Term

- Cost-effective oxygen production from air separation
- Co-firing with biomass
- Ultra-supercritical cycles
- O_2-enriched combustion
- CO_2 recycle
- Fuel preparation
  - Coal cleaning
  - Physical coal cleaning
- Mercury scrubbing
- Operability needs to be a goal from the onset
- Simplicity of design is a desired feature, and should be given high priority in developing technologies for the commercial market

How Can Pulverized Coal Technology Stay Cost Competitive?

- If low cost is not right at the top of the development priority list, then that technology won't be commercially deployed
- Reduce the levelized busbar cost (cost of electricity, COE) by 10 percent
- The capital cost per kilowatt of increased output from repowering should be competitive with the costs for an all new natural gas combined cycle of equivalent capacity. Emissions for retrofit technology should meet NSPS
- Reduce the delivered cost of coal by 15%
- Is there any particular area in PC plants that are the best candidates for lower capital costs through application of improved technology?
- The ability to retrofit for CO_2 capture might become an important concern

Improving Public Outreach

A high priority issue for the attendees was their view that it is critical that the public is informed on realistic climate change messages, so they understand the basis for and consequences of actions on potential climate change issues. The attendees feel that the public needs to understand the consequences of potential political actions on global climate change and the world economy. They are concerned that the public is not getting factually accurate information, and might become driven to press for irrational political actions by rhetoric that has little validity. They worry that some are pressing inaccurate agendas, and this is not authoritatively being counterbalanced. The attendees felt this was an important function that must be given attention.

- Community outreach/education is needed; the power industry does not counterbalance other groups to present a credible industry position on what the costs and implications are of proposed actions

- Provide information so environmental activism is based on a factual understanding of the issues and consequences of proposed actions
- Reverse the public perception-'coal is bad'

If public outreach activities are undertaken, it is felt important to define a metric to measure success for any public outreach/education action.

Exposure to Risk

Projects and environmental actions cost money. Making that investment entails technical and investment risk. Several of the discussions addressed such issues related to project risks:

- Developing approaches that encourage public acceptance
- Working only solutions that are within the limits of the willingness of the public to pay
- Finding ways to reduce the uncertainty in capital recovery
- Investing in coal projects today is risky. The current low price of gas inhibits coal plant selection.
- The projects need to be financially robust, with the ability to operate in a competitive generation market and still meet changing, and ever more stringent local environmental compliance requirements

Regulation Concerns

There was considerable discussion on regulation. There is a perception among some attendees that regulation occurs because, with the advancement of analytical tools, things can be measured, rather than because there is any science behind the supposed regulation. In general, there was a strong message that the regulation is okay if it produces a measurable public good, but that this needs to be proven, before expensive agendas are pursued that in the end would make no change in the problem they were supposed to mitigate. Some of the significant comments included the following:

- There was a strong consensus that a better study of human health impacts is needed. There is an inadequate factual basis for many environmental control regulations. The attendees feel it is important that there be coordination of regulations, and tight linkage with science, identifying damaging sources of pollution, and then developing regulation that is proven to improve health of the general public. They strongly advocate that a rigorous, independent and policy-neutral human health study on the impacts of the various compounds identified as pollutants or potential pollutants should be completed within 5 years.

  This is one of the higher priority issues raised in the Workshop.

- The attendees felt strongly that the goals for environmental regulations should be based on human health risk, not on measuring ability

- There needs to be a better understanding of the implications of regulation to avoid unintended consequences
- There is a strong perception of EPA dominance. Some believes that there is a lack the industry input into their regulatory decision process. The type of comments critical of an EPA that does not respond to real human health needs are reflected in comments that included:
    - How do you get the EPA to address real health issues rather than what some perceive as an EPA political agenda?
    - DOE can act as a factual advocate of industry's position to counterbalance the EPA
- There is a need for the coordination of regulation. Sometimes, fixing one problem may exacerbate another that might have even worse health or economic consequence. A combined compromise approach to multiple goals might prove more reasonable
- Some suggested there is need of a global climate change fall-back position and back-up plan that would address before year 2001 the significant issue of "What do we do, what is the fallback position… if there is no technical/economic solution for mitigating CO_2 emissions into the atmosphere?"

High Temperature Corrosion-Resistant Materials

Materials development is a key issue in any new technology implementation, and as expected, is an important focus of the attendees for future development needs.

The attendees felt there is near and mid-term benefit to increasing materials capability for advanced steam and emerging advanced power cycles. The attendees feel there is advantage in forming a government, industry, and national laboratory partnership to develop the stronger and more corrosion-resistant materials for the upcoming generations of both boiler steam tube and piping applications and for advanced power cycle gas heating applications. The attendees cited the suggested development of materials, which they felt, would be needed that are suited for:

- High pressure 1300°F convective steam heaters mid-term,
- Low pressure 2000-2200°F radiative air heater mid-term, and
- Pilot scale demonstration of a ceramic heat exchanger by 2004

In corrosion-resistant materials, the higher the temperature capability that can be developed at acceptable cost, the better, hence there was some considerable range in the upper bound of temperature capability needed in corrosion-resistant materials. As an example, the mid-term steam heater materials were generally expected in this 1300ºF upper bound temperature regime. While these temperature levels appeared to be a reasonable goal for most attendees, there was a high consensus request for strong, corrosion-resistant steam tube materials suited for much more aggressive temperature conditions: for supercritical boilers having up to 1600°F steam temperature (1800°F-1900°F surface metal temperature).

The attendees noted that it is important in planning the introduction of new materials that the planners understand and include the time steps required to bring a new material to commercial market. Even after successful development and testing, there is still considerable work before a material can be commercially introduced, that is, the full schedule needed before commercial deployment must include the time steps for:

- Development and testing
- Demonstration
- Submission for and receiving code approvals
- Developing the manufacturing infrastructure needed to prepare enough material in sufficient quantity for the potential market
- Developing the distribution network needed to get the materials into industrial application

Developing materials to the point they are code-approved takes time. One important suggestion was developing the procedures that would streamline and accelerate the time needed for the approval process: bringing new materials from successful demonstration to code acceptance in less time.

Materials as Low Cost Solutions.

- Another focus is using new materials that are designed not to improve performance, but instead to reduce cost. Develop materials and/or their use and design in components to perform functionally the same way as today's designs, but with reduced surface area of components needed to perform the required function.
- Another cost-cutting method is to use newer materials to reduce preventative or corrective maintenance costs. It was suggested that ways of using newer high temperature materials be developed as an upgrade for the fleet of existing plants. Here, the goal would be to use the newer material not at rated temperature, but rather use them at the existing unit's lower temperature levels. Since the high temperature material is used at lower-than-rated capability, that could result in a greater margin in material capability to improve corrosion resistance and creep life. The attendees felt that a reasonable goal would be if you could double the life of a component at under twice the cost, you have a winner.

Low Cost Solutions

The panelists discussed several goals for capital and operating cost reductions. These included the following:

- Reduce the levelized busbar cost (cost of electricity, COE) by 10%
- The capital cost per kilowatt of increased output from repowering should be competitive with the costs for an all new natural gas combined cycle of equivalent capacity addition.
- Reduce the delivered cost of coal by 15%

Computer Modeling

Developing computer modeling to verify new technologies prior to demonstration is a high priority concern of the attendees. There is significant interest in exercising these models to understand the impacts of firing opportunity fuels.

- Dynamic modeling of complex cycles, and assessing their control systems and responses to normal and abnormal operations was an important issue
- Better modeling for use as artificial intelligence control / fuzzy-logic and for unit operations optimization was noted as a development need
- Computer modeling of emerging binary cycles is an important development area

The Roles Industry and Government Should Take in Seeing That Technology Needs Are Met: R&D Partnerships and Time-Scale

Exhibit 2 gives a number of possible activities that were discussed. It shows when the break-out session attendees felt they needed implementation. For many of the development activities, this shows the likely partnership roles needed to bring these opportunities through development.

There is concern that the U.S. is supporting research and development that does not match the expected needs of the international market. The feeling is that some of our research and development must be focused on addressing global issues, to encourage that U.S. technology is used and sold overseas to accomplish global goals, and improve U.S. trade.

There is concern that the government is not supporting what the markets want. The markets want simple technology, yet government R&D supports complex technologies

There is also concern about the environmental disconnect between industrialized nations and nations with developing economies. There is concern over regulation decisions, such as on global climate change, which do not fairly apportion responsibilities among nations. There is concern that our nation might develop the wrong technologies for the global goal of emission reduction. There is concern that we might take binding actions that do the U.S. economic harm, while other nations, to their own economic benefit exempt from similar constraint, do actions that cancel any global environmental improvement gain made by our unilateral actions.

Exhibit 2. Activities, the Development Time Scale Needed, and the Likely Partnership Roles Needed to Develop Them

Predominantly Partnership Roles

Activity	Time Scale: near-term to 2005	Time Scale: mid-term 2006-2010	Time Scale: long-term 2011-2015 and beyond	Likely Partnership Role: Govern-ment	Likely Partnership Role: Industry	Likely Partnership Role: Univer-sity	Likely Partnership Role: National Lab
develop/demonstrate high efficiency cycles		2010		●	●		
continue gas turbine topping combustor testing	near term			●	●		
commercialize lower cost oxygen supply systems	near-term			●	●		
demonstrate a coal-fired solid oxide fuel cell-	2004			●	●	●	
health study by CATO institute on the effects of emissions on human health	near-term						
integrated NOx control system demonstration	2003			●	●		
integrated NOx/SOx removal		mid-term					
develop stronger corrosion resistant materials for conventional and advanced steam cycles	near term	mid-term		●	●		●
pilot scale demonstration of ceramic heat exchangers	2004			●	●	●	
bagfilter materials that will collect other contaminants		mid-term					
continued testing of high temperature (1600ºF) particulate filters and systems	near term			●	●	●	
demonstrate low rank coals in boilers	near-term						
establish mercury control for low rank coals	near-term						
develop more/better dynamic modeling of adv. cycles							
develop CO_2 temperature model including effects of water vapor	near-term						
situation analysis, and fall-back position if no technical solution is available to mitigate greenhouse gas	2001			●			
demonstrate CO_2 capture/sequestration	2005			●	●	●	
demo CO_2 absorption/rock-mineralogical sequestration of CO_2	near-term			●			●

APPENDICES

The nine appendices (Appendix A-I) that follow are the source materials for the Summary.

The first six appendixes are the rough notes of each break-out session's scribe. These are the following:

- Appendix A: TUESDAY MORNING June 15, 1999 Group I "1A" Break-Out Session
- Appendix B: TUESDAY MORNING June 15, 1999 Group II "2B" Break-Out Session
- Appendix C: TUESDAY AFTERNOON June 15, 1999 Group I "1C" Break-Out Session
- Appendix D: TUESDAY AFTERNOON June 15, 1999 Group II "2D" Break-Out Session
- Appendix E: WEDNESDAY MORNING June 16, 1999 Group I "1E" Break-Out Session
- Appendix F: WEDNESDAY MORNING June 16, 1999 Group II "2F" Break-Out Session

The seventh appendix, Appendix G, gives some of the information from the summary boards presented by the session scribes at the end of the Workshop:

- Appendix G: Roll-Up Summaries

The material in Appendices A-G is as it was as received from the scribes, or transcribed from the cards they used. Only modest editing to format, spelling, and grammar were made. The content in these appendices represents the raw transcript notes from the scribes and represents the inputs received from the attendees of the break-out sessions.

In some cases, the attendees in a break-out session were asked to record their priority interest areas, generally being given several choices to vote upon. In these appendices, the number of "votes" (understanding that attendees were allowed to vote on more than one issue) are indicated by the number of "stars" (asterisks *). The more "stars" the greater the number of attendees were interested in that issue. The number of "votes" allowed was limited, so not all areas, even important areas, could be voted on. The votes are indicated in this text by the following format, thus, for example:

7*******..............................would indicate that this area received 7 votes, a priority to a greater number of people in that break-out session

3***......................................would indicate this area received 3 votes in that break-out session

0...would indicate that this area received no votes in that session. This does not mean that the issue is not important; the issue was raised in the first place because at least one attendee felt it important; rather, low "vote" count means that the attendees in that break-out session felt that other areas were of more pressing importance.

In all cases, only non-Department of Energy personnel voted on priority issues. DOE refrained from discussing priority, and refrained from influencing any of the prioritization rankings. Later, in Appendix I, these priority rankings are consolidated, and ranked highest to lowest.

The eighth appendix, Appendix H, lists the several hand-written comments and suggestions received from attendees:

- Appendix H: Comments and Suggestions Received from the Attendees

The ninth appendix, Appendix H, has been manipulated by the editor. It reports the priority listings of the attendees from the various break-out sessions, consolidated into logical groupings. These were edited slightly, to make their meaning clearer.

- Appendix I: Panel Discussion Priority Scores Developed by the Attendees, and Their Ranking

- Appendix J: Participant List by Name

Appendix A: TUESDAY MORNING
June 15, 1999

Group I

"1A" BREAK-OUT SESSION

"A" Session scribe: Sean Plasynski

What Are the Major Environmental Issues for the Near -, Mid - and Long - term?

Near - term to 2006

- Mercury issues - challenge of trying to find something that is affordable for mercury control
  - CO_2
  - Energy relationship (efficiency)
- NOx-coupled with the issue that ammonia is not a good thing to have in power plants/meeting NOx reductions without SCRs
- SCR without ammonia
- Particulate PM2.5
- Environmental issues of blended fuels
- Retrofit-cost effectiveness
- Cost effective NOx reduction
- Re-permitting due to NSPS-that anything that you do may require you to re-permit
- Regulatory Interpretation-Specific input from EPA
- Coordination of Regulation
- Greenhouse Gas
- NOx/ Ozone(traces)
- Emissions Practical Limits
- Cross-integration of pollution control - Integrate pollutants within themselves
- EPA dominance - appears that lack the industry input
- Impacts of Competition
- NOx reduction
- Non-deregulation limits / toxic release inventory (TRI)
- Coal mining issues
  - Coal cleaning

    - Waste disposal
- Public perception-'Coal is bad'

Mid-term to 2010

- Regional Haze
- Greenhouse Gas
    - Basic science (w/understanding)
- SO_2 (Acid Gas)
- PM 100 Nanometer (PM-1)
- PM2.5
- Ash character & deposition - in Europe a lot of attention to ash deposition (trace elements)
- Blended Fuels
- Full life cycle analysis
- Coal conversion by-products
- Power distribution siting issues
- 'Carbon' in Energy Taxes
- Mercury issues - challenge of trying to find something that is affordable for mercury control
    - Global
- HAPPS/Air Toxics (heavy metals)
- Water quality

Long-term to 2015 and Beyond

- Greenhouse Gas
- Zero emission concept
- Conflicting New Regulations - i.e. burning gob EPA forgives some toxic release inventory (TRI)
- Dominance of regulators
- New technology distribution infrastructure
- Relative Environmental Performance (based upon fuels-coal vs. others)
- Impacts from CO_2 sequestration- ocean, land (EOR), etc.-all options
- Co-production (co-feed/ complex)
- Environmental Equity

Prioritization of Issues

*Editor's note on the ranking system: the more stars (*), the more those attending the session viewed the item as important*

A key thought to ponder: "If low cost is not right at the top of the development priority list, then that technology will not be commercially deployed."

Near - term to 2006

11 *********** ....NOx-coupled with the issue that ammonia is not a good thing to have in power plants/meeting NOx reductions without SCRs
6 ******..............................Mercury issues - challenge of trying to find something that is affordable for mercury control
- 1 * Global

6 ******..............................CO_2
- 1 * Energy relationship (efficiency)
- 1 * Greenhouse gases

6 ******..............................Retrofit-cost effectiveness
5 ***** ....SCR without ammonia
5 ***** ....NOx reduction-cost effective
5 ***** ....Coordination of Regulation
3 ***....................................NOx/ Ozone (traces)
3 ***....................................Emissions Practical Limits
2 ** ....Re-permitting due to NSPS-that anything that you do may require you to re-permit
1 * ....Impacts of Competition
1 * ....Particulate PM2.5
0...EPA dominance - appears that there is a lack of industry input

Mid - term to 2010

7 ******* ....Greenhouse Gas
- 2 **Basic science (w/understanding)

5 ***** PM2.5
5 ***** ....Full life-cycle analysis
2 ** ....Coal conversion by-products
2 ** ....HAPs/Air Toxics (heavy metals)
1 * ....Power distribution siting issues

Long - term to 2015 and Beyond

4 **** ....Greenhouse Gas
3 ***....................................Impacts from CO_2 sequestration- ocean, land (EOR), etc.-all options
2 ** ....Co-production (co-feed/ complex)
1 * ....Zero emission concept

How Can Environmental Performance be Improved? What Kind of Technology? When Is It Needed?

Near - term: to 2006

5 ***** ....Regulatory Practical Limit toxic release inventory (TRI)
4 **** ....Mercury issues (cost of control)
3 ***....................................NOx-cost effectiveness and retrofit
2 ** ....NOx-SCR
1 * ....Greenhouse gases (CO_2)

Technological Solutions:

Existing Fleet:

5 ***** ....Industry developed evaluation analysis
4 **** ....Mercury scrubbing
4 **** ....Dry injection system
3 ***.....................................Impact of Low NOx burners
3 ***.....................................Optimizing burners - smart control
3 ***.....................................Low temperature catalyst
2 ** ....Ozone injection
2 ** ....Alternative reductant gases
2 ** ....Natural gas reburning
2 ** ....Coal reburning
1 * ....Cofiring with biomass
1 * ....High efficiency repowering
1 * ....Oxygen Enriched Combustion (CO_2 recycle)
1 * ....Cost effective air separation

New Pulverized Coal Plants:

4 **** ....Mercury scrubbing
2 ** ....Oxygen Enriched Combustion (NOx Control)
1 * ....High Temperature Materials
1 * ....Cofiring with biomass
1 * ....Gasification enriched PC
1 * ....Oxygen Enriched Combustion (CO_2 recycle)
1 * ....Ultra-supercritical cycles

- Coal cleaning

Mid term: 2006 to 2010

3 ***.....................................PM2.5
2 ** ....Full Life Cycle Analysis
1 * ....Greenhouse gases

Technological Solutions:

Existing Fleet:

3 ***.....................................Low NOx burners for secondary NOx
3 ***.....................................Increase scrubber efficiency
3 ***.....................................Advanced baghouse materials
3 ***.....................................Advanced pollution control devices
2 ** ....Artificial Intelligence Modeling
1 * ....CO_2 extraction (separation)

New Pulverized Coal Plants:

1 * ....Combined heat and power
2 ** ....Artificial Intelligence Modeling

Long - term: 2010-2015 and Beyond

1 * ....Greenhouse gases

Technological Solutions:

Existing Fleet:

1 * ....CO_2 separation

New Pulverized Coal Plants:

1 * ....Advanced Cycles (binary systems)
1 * ....CO_2 sequestration

Appendix B: TUESDAY MORNING
June 15, 1999

Group II

"2B" BREAK-OUT SESSION

"B" Session scribe: Harvey N. Goldstein

What Are the Major Environmental Issues for the Near -, Mid - and Long - Term?

Brainstorm Issues

- Near - to mid - term NOx vs. visibility criteria
- Regional haze vs. particulates
- Economics
- Near - term NOx / long - term CO_2
- Mercury
- Politics and Publicity
- SO_2
- Impacts on Human Health
- Greenhouse Gas – Reduce, Capture
- Waste ash Utilization
- Permitting Issues for Repowering
- Real Issues vs. EPA Political Agendas
- Define the Real Issues
- Community Outreach and Education
- Thermal Pollution-Water
- Validation of Technical Basis
- Efficiency Improvement
- Total Maximum Daily Load – Water Issues
- Unintended Consequences of Regulations
- Land Use
- Countering Environmental Activists
- Negative Public Perception towards Coal

- Disposal of Solid Waste
- Triggering New Source Performance Standards – EPA Wanting to Do Away with "Grandfathering"
- What is the Real Performance of SCR and SCR Catalysts with U.S. Coals?
- Collateral Damage from Using SCR

NOx Issues (High Priority, Near - to Mid - term)

4**** ....Near - term NOx
3***......................................What is the Real Performance of SCR and SCR Catalysts with U.S. Coals?
2**.......................................Interactions of NOx and Visibility; NOx - SCR
0..Collateral Damage from Using SCR
0..Cost/Availability of SCR

Politically-Related Topics (High, Medium, Low Priority / near -, mid -, and long - term)

3***......................................Permitting for Repowering vs. New Baseload Plants
2**.......................................Community Outreach and Education
1* ....Politics and Publicity
1* ....Keep environmental activists under control
0..Real Issues vs. EPA Political Agendas
0..Environmental Activism, Hg

Government Regulations (High, Medium, Low Priority / Near -, Mid -, and Long - term)

7******* ....Better Study of Human Health Impacts
2**.......................................Triggering New Source Performance Standards – EPA Wanting to
1* ....Emissions Caps on New Capacity
0..Unintended Consequences of Regulations
0..Do Away with "Grandfathering"
0..Government Regulations
0..An issue is defining just what the issues are
0..There is need for validation for the premise that leads a regulation

Waste Products (High Priority)

0..Water Intake/Discharges

Waste Products (High Priority, near-term)

2**.......................................Waste Ash Utilization
0..Water Intake / Discharges
0..Total Maximum Daily Load (TMDL) – Water Issues
0..Disposal of Ash and Solid Waste
0..Land Use

Hazardous Air Pollutants (HAPs) / Particulate Matter (High Priority, Near - term)

6******...............................Regional haze (3***) vs. particulates (3***)
1* ....Mercury
1* ....SO_2, SO_4

Climate Change (Medium to Low Priority, Mid - to Long - term)

6******...............................Long - term CO_2 emissions
3***......................................Global Greenhouse Gas concems, all greenhouse gases
2**..Greenhouse Gas – Reduce, Capture, Sequester

Cross-Cutting Issues (Near - term)

8******** ....Efficiency Improvement
7*******.............................Cost / Economics
5*****.................................Systems Integration

>>>editor comment: Issues apparently lost in the shuffle<<<

- *Near to mid - term NOx vs. visibility criteria*
- *Economics*
- *Politics and Publicity*
- *Impacts on Human Health*
- *Thermal Pollution-Water*
- *Validation of Technical Basis*
- *Efficiency Improvement*
- *Countering Environmental Activists*
- *Negative Public Perception towards Coal*

SOLUTIONS: What Should the Goals Be (Cost, Performance, Other) for Modifications to the Existing Fleet?

(for existing units only) =??? (for both existing units and new units) = ?? (for new units only) = ??

Cross-Cutting Issues

- Advanced technology / cycles *(for both existing units and new units)*
- Use of supercritical steam cycles *(for new units only)*
- Better materials / high-temperature materials *(for both existing units and new units)*

- More demonstrations *(for both existing units and new units)*
- Lower Costs *(for both existing units and new units)*
- Better Modeling *(for both existing units and new units)*

High Temperature Materials

3***......................................Use newer high temperature materials as an upgrade in an existing plant, but use these at the existing unit's lower temperature levels. Since the high temperature material is used at lower-than-rated capability, use the resulting greater margin in material capability to improve corrosion resistance. A reasonable goal would be to double the life at under twice the cost.

Pilot- and Commercial-Scale Demonstrations

9********* ....Develop technologies that provide a 20 percent energy efficiency improvement
6******...............................Provide commercial, full-size demonstrations

Low Cost Solutions

2** ....Repowering technology capital cost should be competitive with that for installing a new natural gas combined cycle of equivalent capacity
1* ....Reduce the cost of electricity by 10 percent
1* ....Lower the delivered cost for coal by 10 percent
0* ....Repowering must conform to NSPS

Computer Modeling

0...Develop new modeling techniques (goal not defined)
0...Develop computer models to ascertain the impact of co-firing of opportunity fuels, showing the environmental and operational characteristics

Greenhouse Gases and Climate Change

6******...............................Develop technologies supporting the increased use of biomass (for both existing and new units) to 10-20 percent fraction with coal
0...Sequesterization (for both existing units and new units)
0...Capture (for both existing units and new units)
0...Low Net CO_2 Emissions (for both existing units and new units)
0...Improve Existing Fleet (for existing units only)
0...CO_2 Recycle with O_2 Combustion (for existing units only)

HAPS / Particulate Matter

- High temperature / high efficiency filters *(for both existing units and new units)*

NOx

- Chemical sorbents for NOx (for both existing units and new units)
- Combustion Modification (for existing units only)
- Fuel Blending / co-firing (for both existing units and new units)

7******* ....Develop low-temperature (about 300ºF) SCR catalyst to remove 90 percent of NOx by year 2003
6******...............................Remove 95 percent of NOx from combustion turbines by year 2003

5*****..................................Develop materials/designs that allow 5-year life for waterwalls under low NOx burner conditions
3***.......................................Develop NOx control methods with a cost target of less than $500/ton NOx
2**...Attain a NOx level of 0.1 lb / 10^6 Btu
1*...Low NOx burners (for both existing units and new units)
0...O_2 for NOx control (for both existing units and new units)

Waste Products

Government Regulations

7*******.............................A rigorous, independent human health study on the impacts of the various compounds identified as pollutants or potential pollutants should be completed within 5 years. The goals for environmental regulations should be based on human health risk, not on measuring ability. (this impacts the future for both existing units and new units)

Political Issues

6******...............................The public needs to be provided with realistic messages on climate change
0...More / improved public outreach is needed (affects both existing units and new units)
0...There is a need to define a success criteria (metric) for public outreach

Appendix C: TUESDAY AFTERNOON June 15, 1999

Group I

"1C" BREAK-OUT SESSION

"C" Session scribe: Sean Plasynski

Review of the Last Session – What are the Technological solutions? Any Additions?

- Fuel preparation – physical coal cleaning (near - term: existing/new: fuel preparation to reduce greenhouse gasses – CO_2)

Session 1C: Definition of Cost and Environmental Performance Goals for Existing Fleet to Keep Pulverized Coal Technology Competitive

What modification to the existing fleet can help address future cost and environmental performance issues?

What are the system goals for existing pulverized coal to meet environmental challenges?

Greenhouse Gases (CO_2)

- CO_2 recycle – lower cost of oxygen by 20%
- New pulverized coal design to achieve 1% air leakage at today's cost
- Ultra-supercritical cycle

NOx – SCR Short -term

- A target of 0.10 lb/10^6 Btu
- A target cost around $70/ton NOx; today's range: $70 to $200 / ton NOx, $90 /ton NOx reasonably typical

NOx – Without SCR Mid - term

- Ozone Injection – emissions as low as natural gas
- Today coal is about 0.12 lb/10^6 Btu to mid 0.05 lb/10^6 Btu.

- Long - term, need to be the same as natural gas, single digit (ppm) NOx, at a cost of no more than \$100/kW
- Cost Effective NOx Retrofit needed

Mercury Issues

- Mercury scrubbing – suggested target is for a 70 % reduction at a cost below about \$20,000/lb mercury, to be achieved mid - term *(???editor question: should this be \$20,000/ton???)*
- EPA has a goal of 1.0 – 2.0 mills/kWh
- Dry injection systems

PM2.5

- Increased scrubber efficiency – PM2.5 as sulfur, then \$150/kWh at 95% sulfur removal

Other

- Discussion on just what people would be willing to pay – how will this affect the definition of goals, etc.
- Overall modification cost to be less than a new combed cycle plant.
- Low cost natural gas (along with cheap capital equipment for its use) makes it difficult to push the goals of the coal plants.

What are the roles for industry and government in seeing that the technology needs are met? What R&D partnership roles can be identified?

Industry

- Host testing program – testing of new technologies
- Industry feed-back – technology transfer of data; reality checks for government

Government

- Basic science and engineering technology (no low technology problems, just low tech solutions)
- Significant public benefit - CO_2, NOx reduction, lower cost of electricity
- Higher risk technologies – carbon sequestration technology
- Technologies for mid- and long-term
- Quantify public health issues
- Establish technology issues and barriers
- Set complete (up-front) and consistent rules
- State governments to help entrepreneurs in assistance of bringing technology to markets
- DOE should develop a good scientific database of information

Partnerships

- New technology standards
- Develop a new round of demonstrations, with the Clean Coal Technology Demonstration program as the model
- NIH / EPA / DOE partnerships
- Advisory groups

Other Comments

- Does industry mean two different groups? Power producers and equipment suppliers, with divergent goals? One group would not like to see more regulation, while the other would like to sell more equipment
- Cost-sharing: cost sharing should depend on the general cost / benefit / risk for each project. Cost sharing is hard to get now, because of deregulation, since many utility companies are being sold or have recently been acquired, and are replacing / upgrading the newly purchased assets
- Example: Mercury Control: Partnerships: sorbent R&D Cost-Share – demo / site host. Government: should test demonstration mercury control technologies

Appendix D: TUESDAY AFTERNOON
June 15, 1999
Group II
"2D" BREAK-OUT SESSION

"D" Session scribe: Harvey N. Goldstein

Tuesday PM-Goals

Existing-Plants

Technologies that apply to existing plants:

Definition of existing plant: Spending more than some threshold of money ($400/kWe) on plant improvements. If you spend more, this fits into the category of "new" plant. Repowering with advanced technologies as per the DOE study means new in this context.

What level of investment are owners willing to put into an existing plant

1-High Temperature Materials

- High pressure convective air heater to 1300°F; low pressure convective air heater to 2100°F – Replaced by Improved corrosion resistance for superheater parts
- Develop materials that double life at a cost less than 2-times that of original
- Use high temperature materials in an existing plant, at the lower existing plant temperatures to decrease corrosion, improve reliability, and reduce maintenance costs

2-Pilot- and Commercial-Scale Demonstrations

- The goal should be to improve the energy efficiency for existing plants by an amount that reduces fuel used for each kilowatt generated by 20 %, that is, improve the Btu/kWh heat rate by 20 % about the same as an energy efficiency increase of about 7 percentage points)
- Demonstration needs to be at no less than ½ scale of commercial size for some items, or full scale of a module for other things. Depends on the item

3-Low Cost Solutions

- Reduce the levelized busbar cost (cost of electricity, COE) by 10%

- The capital cost per kilowatt of increased output from repowering should be competitive with the costs for an all new natural gas combined cycle of equivalent capacity addition
- Emissions for retrofit technology should meet NSPS
- Reduce the delivered cost of coal by 15%

4-Computer Modeling

- Develop computer model that assesses the impacts of firing opportunity fuels
- Better modeling is a general need — goal undefined

5-Increased Use of Biomass

- Increase burning biomass in co-firing or reburn to 10% biomass fraction
- Increase biomass co-firing to 20% biomass fraction

6-Fuel Blending/Switching

- NOx control below $500/ton NOx
- Set 0.10 lb/10^6 Btu of NOx as a goal
- Develop low temperature SCR (less than 300°F) to take out 90% NOx by 2003

7-Combustion Modifications - Low NOx Combustion, New Burners, Oxygen for NOx Control

- NOx control below $500/ton NOx
- Set 0.10 lb/10^6 Btu of NOx as a goal
- Extending life of water walls to 5 years in units employing low NOx combustion
- Develop low temperature SCR (less than 300°F) to take out 90% NOx by 2003

8-Chemical Sorbents for NOx

- NOx control below $500/ton NOx
- Set 0.10 lb/10^6 Btu of NOx as a goal
- Develop low temperature SCR (less than 300°F) to take out 90% NOx by 2003
- Develop a chemical sorbent to remove 95% of NOx from combustion turbine exhaust by 2003

9-Rigorous Human Health Study

- Goals based on human health rather than technology
- Health study completed in 5 years

10-More/Better Public Outreach

- Define a metric for success for public outreach/education
- Provide realistic climate change messages

Most Popular Items-Roles for Industry, Government, Academia

- Remove 95% of NOx from combustion turbines by 2003 - use the DOE's Power System Development Facility (PSDF) in Wilsonville Alabama to test a variety of equipment from different gas turbine manufacturers
- Develop a 300°F SCR Catalyst - 20% government, cost share determined by level of risk, government for development, industry for testing
- Develop five-year life for low-NOx burner waterwalls, etc. - government/industry test facility - new or existing
- Develop 20% Biomass co-firing - continue NREL participation, government/industry partnership
- Fund commercial-size demonstrations - government/commercial partnership with cost participation dictated by the level of risk
- Improve the energy efficiency of power generation as a government/industry partnership, so that 20% less fuel is wasted per kilowatt (that is, improve the heat rate by 20%, about a 7-percentage point improvement in energy efficiency compared to today's units).
- Expand the scope of the PM2.5 and mercury monitoring study, so that there is an adequate base of data to make decisions. Ensure consistent fine particulate monitoring, so that the data fits with the needs of the health study. Complete a rigorous health study in 5 years-100% Government role, NIH does the study using 100% government funding, expand scope of PM-2.5 and mercury study
- Fine particulate monitoring must be done consistently … the testing methodology and analysis must be consistent between the DOE, EPA, EPRI, etc., so that the database is correct for the NIH health studies. You must measure the right thing; be sure you measure what is suspected of being the health-affecting compounds, not just what is easy to measure. Insure consistent fine-particle monitoring. There is a large government role with some industry involvement

  What good does it do to regulate an easy-to-find target, if it turns out that it is the wrong target to improve health? Measure adequately so that you can determine what, ultimately, is the source of health-damaging emissions. If, for example, it is truck diesels, regulate them… if it is utility companies, regulate power generators. If you regulate the wrong target, people are still going to be getting. How do you find the right target to regulate?
- Provide a realistic climate change message - Government, NSF, University effort

Appendix E: WEDNESDAY MORNING June 16, 1999

Group I

"1E" BREAK-OUT SESSION

"E" Session scribe: Sean Plasynski

R&D Needs for New PC Plants

What are the technical barriers for new PC plants in the U.S. and in developing countries? – Near -, mid - and long - term

- Code Approval for Material Development – reduce the time needed for coding materials
- Higher temperature materials
- Cost - still needs to be competitive with natural gas combined cycle
- CO_2 sequestration issues
- Increased corrosion resistance of materials
- Air separation -Low cost, improved technology separation methods
- Pulverizer Improvements - lowering power consumption, reducing cost
- Mixed fuels - use of waste fuels, agricultural fuels, biomass, etc.
- Cost of materials and other components, reduce the surface area of components
- Coal combustion characteristics of indigenous fuels of foreign countries; there is a lack of combustion data, lack of combustion experience with these coals
- Quality control/quality assurance in international market
- Waste disposal and byproduct utilization in foreign countries
- Controls of complex cycles (integration of steam and gas cycles)
- Emission controls for non-criteria pollutants
- Risk of new technology

What R&D activities in systems, equipment and materials are required to overcome barriers?

- Intelligent control/fuzzy logic and optimization
- Advanced material development for 1600 degrees F steam (corrosion resistance)
- Materials development for 2000 degrees F

- Reducing heat losses in condensers
- Advanced coal cleaning - for ash reduction
- Full Characterization of fuel - i.e. arsenic is a catalyst poison, need to know if coal has these components; mercury removal technology development; including blended fuels, biomass & utilization of blended fuels and biomass
- Binary cycling modeling
- Dynamic modeling of complex cycles
- Fundamental research on CO_2 sequestration
- Membrane technology separation - (air separation)
- Ability to Cycle PC plants
- Advanced Slagging Combustion Technology - [developing countries waste problem] low NOx, high ash fuels
- Oxygen enriched combustion technology
- Modeling and verification of new technologies (prior to demonstration)

PRIORITIZE

21********************* Full Characterization of fuel - i.e. arsenic is a catalyst poison, need to know if coal has these components; mercury removal technology development; including blended fuels, biomass and the utilization of blended fuels with biomass

13*************.............Advanced material development for 1600 ºF steam (corrosion resistance)

6******..............................Modeling and verification of new technologies (prior to demonstration)

6******..............................Membrane technology separation - (air separation)

5*****................................Materials development for 2000 ºF

4****..................................Dynamic modeling of complex cycles

4****..................................Fundamental research on CO_2 sequestration

3***.....................................Advanced coal cleaning - for ash reduction

3***.....................................Ability to Cycle PC plants

3***.....................................Advanced Slagging Combustion Technology - [developing countries waste problem] low NOx, HIGH ash fuels

2**.......................................Artificial Intelligent control/fuzzy logic and optimization

0...Turbine / condenser improvement (reduce heat losses)

What R&D partnership roles can be identified?

- Utilization of condensing eat exchanger (waste heat utilization)
- Basic Research (university)
- International Partnership - biofuel Database (government)
- USDA & USFS (government to government) fuel preparation
- Teaming with Trade Development Agency (TDA) - co-develop mission (government)
- Industrial consortium with DOE (Office of Science and FE) coordinated by ORNL or FETC
- Industry advisory groups for advice on basic research projects (esp. with universities)
- Scoping workshop using in-kind advisory panel from industry

Appendix F: WEDNESDAY MORNING June 16, 1999

Group II

"2F" BREAK-OUT SESSION

"F" Session scribe: Harvey N. Goldstein

New plants in US and Developing countries

Technical Barriers for New PC Plants

- Materials
- Operability
- Improved Efficiency-Better Performing cycles
- Environmental vs. cost tradeoff
- Ability to operate in competitive market
- Public acceptance
- Capital cost
- Environmental disconnect - US vs. undeveloped countries
- Markets want simple technology-R&D supports complex technologies
- Gas turbine low NOx combustors
- Improved turbine cycle and efficiency
- Improved bottoming cycles
- Improved burner performance for difficult fuels
- Low price of gas
- Integrated NOx and mercury control
- Ability to retrofit for CO_2 capture
- Environmental offset/credit system
- Measuring mercury
- Simplicity in design
- Reliability/accuracy of CEMS
- Controlling acid gases
- High temp particulate filters-near term (1600ºF and above)
- Pulverizer/classifier for mixed fuels

- Capital recovery uncertainty

Categories

- Crosscutting
- Government Regulations and Political
- Global Climate Change
- NOx
- HAPs and PM

- Develop/demonstrate high efficiency cycles
- Stronger corrosion resistant materials for steam cycles - mid - term
- Demonstrate CO_2 capture/sequestration by 2005
- Commercialize lower cost oxygen supply systems - near - term
- Bagfilter materials that will collect other contaminants - mid -term
- Demonstrate a coal fired solid oxide fuel cell-2004
- Health study by CATO institute - near - term
- Integrated NOx control system demonstration 2003
- CO_2 temperature model including water vapor - near - term
- Continued topping combustor testing - near - term
- Integrated NOx/SOx removal - mid - term
- Fallback position if there is no technical/economic solution for CO_2 - 2001
- Pilot scale demo of ceramic heat exchanger by 2004
- CO_2 absorption in rock-mineralogical demo - near - term
- More/better dynamic modeling of advanced cycles
- Demo of low rank coals in boilers near - term
- Mercury control for low rank Coals - near - term

Government Roles

- Demo high efficiency cycles-partnership
- Demo CO_2 sequestration by 2005-government/industry
- Situation analysis-government
- HITAF-government/industry/academia
- Oxygen separation-government/industry
- Stronger corrosion resistant materials - government labs/industry (in-situ)
- SOFC testing with coal-government and industry/academia fir testing
- CO_2 capture-government/industry/academia
- Generic remark-anything needing more than 2 years-funded by government
- Integrated NOx control-government/industry
- Topping combustor & particulate filter-government/industry

Of the role of government, one attendee made the statement:

> "Anything needing more than two years to develop should be funded by government."

Appendix G:
Group I & Group II Combined
Roll-Up Summaries

At the end of the Workshop, the scribes summarized the results from their break-out sessions. These are recorded in this appendix.

Summary of R&D Activities Board 1: What are the Technical Barriers for New Pulverized Coal Plants (U.S. and Developing Nations)?

- Bottoming binary cycles
- Improved efficiency
- Improved turbine cycle and efficiency
- High temperature particulate filters
- Improved burner performance
- Pulverizer and classifier improvements
- Technology demonstration
- Operability
- Materials
- Simplicity of design
- Accuracy and reliability of continuous emission monitors (CEMs)
- Method of measuring Hg
- Ability to retrofit for CO_2 capture
- Low NOx combustors for gas turbines
- Integrated NOx and Hg control
- Environmental disconnect between industrialized nations and developing nations
- Ability to operated in a competitive generation market and still meet local environmental compliance requirements
- Domestic environmental compliance/cost trade-off
- Credit system for environmental off-set
- Controlling acid gases
- Public acceptance
- Capital cost
- Uncertainty in capital recovery

- Willingness of the public to pay
- Current low price of gas inhibits coal plant selection
- We are supporting research and development that does not match the expected needs of the international market

Summary of R&D Activities Board 2: What R&D Activities Are Needed to Overcome Barriers?

Crosscutting

- Higher efficiency power plants, changing cycles

11*********** ....Develop/demonstrate high efficiency cycles - partnership

- Use of supercritical steam cycles
- Pilot and commercial scale demonstrations

3***......................................Demonstrate a coal fired solid oxide fuel cell-2004 with coal-government and industry/academia for testing
3***......................................Pilot scale demo of ceramic heat exchanger by 2004
2**..Demonstrate the use of low rank coals in advanced power systems

- Low-cost solutions
- High-temperature materials

5***** ....Stronger corrosion resistant materials for advanced steam cycles - government labs/industry (in-situ)
2**..High pressure 1300°F convective steam heater mid - term
2**..Low pressure 2200°F radiative air heater mid - term

Computer Modeling

1* ....Temperature projection modeling that includes water vapor – near - term
1* ....Transient analysis of HIPPS cycles

Government Regulations and Political

- Cooperation between U.S. and other governments

3***......................................What do we do, what is the fallback position… if there is no technical/economic solution for CO_2 - 2001
1* ....Policy-neutral health study by CATO Institute - near - term

Global Climate Change

- CO_2 capture (b)

7******* ....Demonstrate CO_2 capture system by 2005

- CO_2 sequestration (b)

5***** ....Demonstrate CO_2 sequestration system by 2005
3***......................................Demonstrate CO_2 absorption in rock-mineralogical - near - term

- CO_2 recycle with O_2 combustion

7******* ....Commercialize lower cost oxygen separation systems - near - term

- Improve CO_2 intensity of existing fleet, of fleet replacements/upgrades/repowering capacity, and of new generation capacity
- Low net CO_2 emission

NOx

4**** ....Integrated NOx control system demonstration - government/industry partnership - 2003
2**...Burner development – near - term
5***** ....Continued topping combustor testing - near - term

- Chemical sorbents for NOx (b)

2**...Integrated NOx/SOx removal - mid - term

HAPs and PM

2**...High temperature, high efficiency particulate filter
1* ....Bagfilter materials that will collect multi-contaminants - mid - term
3***.......................Continued testing of high temperature (1600ºF) particulate filter – near - term
2** ....Mercury control for low chlorine coals - 2005

Summary of R&D Activities Board 3: What Are the Technological Solutions?

NOx (Near - term Concern)

- Chemical sorbents for NOx (b)
- Low-NOx combustion, new burners (b)
- Oxygen for NOx control (b)
- Fuel blending, co-firing, fuel switching (b)
- Combustion modification (e)

Waste Products (Near - term Concern)

Hazardous Air Pollutants (HAPs) and Particulate Matter (Near - term Concern)

- High temperature, high collection efficiency particulate filters (b)

Cross-Cutting: Efficiency, Cost, System Integration (Near - term Concern)

- Higher efficiency power plants; changing cycles (b)
- Use of supercritical steam cycles (n)
- High temperature materials (b)
- Pilot- and commercial-scale demonstrations (b)
- Low cost solutions (b)

- Dynamic computer modeling of plants; computer modeling (b)

Global Climate Change (Mid - to Long -term Concern)

- Sequestration (b)
- CO_2 capture (b)
- Low net CO_2 emission (b)
- Increased use of biomass (b)
- CO_2 recycle with O_2 combustion for existing fleet (e)
- Improve CO_2 intensity of existing fleet (e)

Politically-Related Topics (Near -, Mid -, and Long - term Concern)

- More and better public outreach (b)

Government Regulations (Near -, Mid -, and Long - term concern)

- Rigorous human health study (b)

What are the Near - term Technological Solutions?

Existing Fleet – Near - term

Greenhouse Gases

Includes public perception and energy relationship

- Co-firing with biomass
- High-efficiency repowering
- Natural gas reburning

NOx Control with Selective Catalytic Reduction (SCR)

- Ozone injection
- Alternative reductant gases
- Coal reburn

NOx Control: Cost Effect and Retrofit

- Improve low NOx burners
- Develop low temperature catalyst
- Optimize burners with smart controls

Mercury Control Issues (Cost of Control)

- Hg scrubbing
- Dry injection systems

Regulatory Practical Limit – Toxic Release Inventory

- Industry-developed evaluation analysis

New PC Plants – Near - term

- Cost-effective oxygen production from air separation
- High temperature materials
- Co-firing with biomass
- Gasification-enriched pulverized coal
- Ultra-supercritical cycles
- O_2-enriched combustion
- CO_2 recycle
- Fuel preparation
  - Coal cleaning
  - Physical coal cleaning
- Mercury scrubbing

What are the Mid - term Technological Solutions?

Existing Fleet – Mid - term

PM-2.5

- Low NOx burners (secondary effect)
- Increased scrubber efficiency
- Advanced baghouse (material)
- Advanced APCD (for example, the CuO process)

Greenhouse Gases

- CO_2 extraction / separation

Full Life-Cycle Analysis

- Artificial intelligence modeling

New PC Plants – Mid - term

- Binary system, advanced cycles
- CHP
- Artificial intelligence modeling

What are the Long - Term Technological Solutions?

Existing Fleet – Long - Term

- Greenhouse gas separation

New PC Plants – Long - Term

- Binary system, advanced cycles
- CO_2 sequestration (all options)

Appendix H: Questions and Suggestions Received from the Attendees for Panel Sessions

During the Workshop Panel Sessions, a number of questions/suggestions were tendered. This appendix provides some of these comments, as received, from the Wednesday Session on the theme " A future for new PC plants in the U.S. and abroad B Mid-term technology concepts with reduced capital and operation costs, superior environmental performance, and increased efficiency."

Comment PL-1

- Is there any particular area in PC plants that are the best candidates for lower capital costs through application of improved technology?
- Showed GTCC as 0.1 NOx?
- Performance of copper oxide system.
- B&W Goals…When?

Net HHV energy efficiency ....>50%
NOx ....< 0.15 lb/10^6 Btu
SO_2 reduction..> 95%
Particulate collection ....> 99.9%
Hg removal..> 90%

- Is 1400°F steam temperature achievable?

Comment PL-2

To Dennis McDonald – B&W

Is reduction of the cost of plant systems and components a government role?

Comment PL-3

To Peter Tortorelli - ORNL:

How soon do you think materials may be available for supercritical boilers at 3600 psi and 1600°F steam temperature (1800°F-1900°F surface metal temperature) which will also have corrosion resistance?

Comment PL-4

To Roderick Beittel – D. B. Reily Inc.

1) Is pulverized coal reburn a viable low NOx retrofit?

2) If so, what reductions have been achieved or projected as a potential reduction range?

Comment PL-5

Is there anyone w/opinion? Is the Kalina cycle – the ammonia/water binary cycle – cost effective? i.e., do the high surface area requirements pay out for the incremental efficiency improvement?

Comment PL-6

To Mike DeLallo – Parsons Infrastructure & Technology Group Inc. and others

Do you see a trend toward tight integration of Brayton and Rankine cycles to achieve high efficiency in future power generation equipment?

Comment PL-7

Conceptual Question to Anyone…

If you could provide a zero discharge PC plant, beyond today's environmental performance, what incremental capital cost would the market bear?

$200/kW?
$100/kW?
$0/kW?

(Not including CO_2 in zero)

Comment PL-8

To Rod Beittel – D. B; Riley Inc.:

What percentage of U.S. coals have slagging characteristics suitable for combustion in the LEBS U-fired boiler?

Comment PL-9

For: United Technologies

Refractory is notoriously high maintenance. What will happen to the radiant air heater tubing if refractory spalls locally and the tubes are exposed to the slag (corrosion?).

There are several bubbling bed PFBC's operating in the world. Where do they fit into these studies?

Comment PL-10

To Dennis McDonald – B&W

What were your annual average capacity factor and economic life (evaluation period) for your PC vs. NGCC economic comparison??

Comment PL-11

To Peter Tortorelli - ORNL

Discuss the steps and time required to bring a new material to commercial market, that is:

- Testing
- Demo
- Code
- Manufacturing.
- Distribution

Comment PL-12

To Dan Seery – United Technologies Research Center

With HIPPS technology, using supplemental natural gas, is there such a thing as an "optimum" natural gas cost? Is higher better, due to the natural gas combined-cycle bogie?

Comment PL-13

How does fuel preparation and efficiency improvements fit into the picture of Technology Development?

- What are the barriers?

Appendix I: The Priority Scores Developed by the Attendees and Their Ranking

Introduction

This appendix gives some electric power industry opinions of priority for a number of issues relating to pulverized coal combustion technologies. These were developed at the U.S. Department of Energy (DOE) sponsored Workshop, "Power Production in the Next Century" Workshop held on June 15-16, 1999 in Arlington, Virginia. The Workshop focused on the evolution of pulverized coal (PC) combustion technology.

Highest Priority Items Noted by the Industry Attendees

In many cases, the industry attendees were given the opportunity to prioritize goals and issues. The list below gives those issues with the highest interest levels indicated by the attendees. The more "stars" (*), the greater the number of attendees felt this was a key issue. When the attendees in a break-out sessions were asked to record their priority interest areas, they were given several "votes" that they could use to assign priority. They might have six votes total. They could place all six "votes" on one single issue, or spread their "votes" among several issues. The number of "votes" each issue received are indicated by the number of "stars" (asterisks*), one "star" per "vote." The more "stars" the greater the number of attendees were interested in that issue. The number of "votes" allowed was limited, so not all areas, even important areas, could be voted on. The votes are indicated in this text by recording the "stars" format, thus, for example:

7*******....................would indicate that this area received 7 votes, a priority to a greater number of people in that break-out session

3***............................would indicate this area received 3 votes in that break-out session

0.................................would indicate that this area received no votes in that session. This does not mean that the issue is not important; the issue was raised in the first place because at least one attendee felt it important; rather, low "vote" count means that the attendees in that break-out session felt that other areas were of more pressing importance.

In all cases, only non-Department of Energy personnel voted on priority issues. DOE refrained from discussing priority, and refrained from influencing any of the prioritization rankings.

Higher Priority Issue Cut Point. The editor felt it best if the issues were broken into a higher priority grouping and lower priority grouping. This was done by separating those comments that were prioritized by the attendees in any of the six break-out sessions. These were separated from highest (a single activity that received 21 "votes" or "stars") to lowest number of "votes," (a number of suggestions received 0 "votes"). The editor chose as his ranking break-point to separate the issues into an approximate "upper third" and into a "lower two-thirds" of comment votes.

There were several hundred issue comments developed during the Workshop. Of these, in total, there were 155 that were prioritized issues tendered by the attendees.

The author's choice of the 1/3 – 2/3 break point occurs at about the boundary between those 1/3 "higher priority" issues with four or more "votes" or "stars," and the lower 2/3 issues that received three or fewer "votes."

In this appendix, those in the lower 2/3 grouping are shown in italics, with a light background shading.

Higher Priority Issues Are Not the Only Important Issues. While a high priority level indicates high interest, they are largely a "popularity contest." That is, it tends to reflect current industry pressures and needs. There were also many other issues and comments raised. The higher priority list items are of obvious importance the power industry, and represent efforts that would develop products that industry wants.

While in general, high priority issues should attract support, it is also imperative that not all of the low priority issues be rejected. While most should receive limited attention, some, a limited few, represent new or innovative approaches that could possibly have far-reaching consequences if developed. The reader needs to understand that there might be value to low-ranked issues. These might lead to solutions that industry needs, but does not yet adequately understand, high risk perhaps, but high potential gain.

Major Environmental Issues, Technical Solutions

6******......................Retrofit-cost effectiveness as a choice for environmental emission intensity (tons/kW) improvement – near - term to 2006

5*****........................Full life-cycle analysis of environmental solutions – mid -term to 2010

*3***............................Emissions practical limits – near - term to 2006*

*3***............................Existing Fleet: Advanced pollution control devices needed mid - term: 2006 - 2010*

*2**..............................Coal conversion by-products – mid - term to 2010*

*2**..............................Co-production (co-feed/ complex) – long - term to 2015 and beyond*

*2**..............................Full Life Cycle Analysis of environmental control system - mid - term: 2006-2010*

1................................Impacts of Competition – near - term to 2006*

1................................Power distribution siting issues - mid-term to 2010 – long - term to 2015 and beyond*
1................................Zero emission concept – long - term to 2015 and beyond*
1................................Existing Fleet: Cofiring with biomass needed near - term to 2006*
1................................Existing Fleet: High efficiency repowering needed near - term to 2006*
1................................Existing Fleet: Cost effective air separation needed near - term to 2006*
1................................New Pulverized Coal Plants: Gasification enriched PC needed near - term to 2006*
1................................New Pulverized Coal Plants: Ultra-supercritical cycles needed near - term to 2006*
1................................New Pulverized Coal Plants: Combined heat and power needed mid - term: 2006 - 2010*
1................................New Pulverized Coal Plants: Advanced Cycles (binary systems) needed long - term: 2010 - 2015 and beyond*

Crosscutting R&D Activities Needed to Overcome Barriers

21*********************
Full Characterization of fuel - i.e. arsenic is a catalyst poison, need to know if coal has these components; mercury removal technology development; including blended fuels, biomass and the utilization of blended fuels with biomass
8********..................Efficiency Improvement- near - term
7*******....................Cost / Economics- near - term
5*****........................Systems Integration- near - term
*3***............................Advanced coal cleaning - for ash reduction*
*3***............................Ability to Cycle PC plants*
*3***............................Advanced Slagging Combustion Technology - [developing countries waste problem] low NOx, HIGH ash fuels*
*2**..............................demonstrate the use of low rank coals in advanced power systems*
0.................................Turbine / condenser improvement (reduce heat losses)

Government Regulations and Political

7*******....................A rigorous, independent human health study on the impacts of the various compounds identified as pollutants or potential pollutants should be completed within 5 years. The goals for environmental regulations should be based on human health risk, not on measuring ability. (this impacts the future for both existing units and new units)
7*******....................Better Study of Human Health Impacts

6******......................The public needs to be provided with realistic messages on climate change
5*****........................Coordination of Regulation – near - term to 2006
*3***............................What do we do, what is the fallback position… if there is no technical/economic solution for CO_2 - 2001*
*3***............................Permitting for Repowering vs. New Baseload Plants*
*2**..............................Community Outreach and Education*
*2**..............................Triggering New Source Performance Standards – EPA wanting to do away with "Grandfathering"*
*2**..............................Re-permitting due to NSPS-that anything that you do may require you to re-permit – near - term to 2006*
1................................Policy-neutral health study by CATO institute - near - term*
1................................Emissions Caps on New Capacity*
0.................................Unintended Consequences of Regulations
0.................................Do Away with "Grandfathering"
0.................................Government Regulations
0.................................An issue is defining just what the issues are
0.................................There is need for validation for the premise that leads a regulation
0.................................More / improved public outreach is needed (affects both existing units and new units)
0.................................There is a need to define a success criteria (metric) for public outreach
0.................................EPA dominance – the EPA appears that lack the industry input; get EPA under control - near - term to 2006

Pilot- and Commercial-Scale Demonstrations

11***********..........Develop/demonstrate high efficiency cycles - partnership
9*********................Develop technologies that provide a 20 percent energy efficiency improvement upgrade to existing plants
6******......................Provide commercial, full-size demonstrations
*3***............................Demonstrate a coal fired solid oxide fuel cell - 2004 with coal-government and industry/academia for testing*

Low Cost Solutions

*2**..............................Repowering technology capital cost should be competitive with that for installing a new natural gas combined cycle of equivalent capacity*
1................................Reduce the cost of electricity of existing plants by 10 percent*
1................................Lower the delivered cost for coal by 10 percent*
0................................Repowering must conform to NSPS*

Computer Modeling

6******......................Modeling and verification of new technologies (prior to demonstration)
5*****........................Existing Fleet: Industry developed environmental evaluation analysis - near - term to 2006
4****..........................Dynamic modeling of complex cycles
*2**.............................Artificial Intelligent control/fuzzy logic and optimization*
*2**.............................Existing Fleet: Artificial Intelligence environmental modeling needed mid - term: 2006 - 2010*
*2**.............................New Pulverized Coal Plants: Artificial Intelligence Modeling needed mid - term: 2006 - 2010*
1...............................Temperature projection modeling that includes water vapor – near - term*
1...............................Transient analysis of HIPPS cycles*
0.................................Develop new modeling techniques (goal not defined)
0.................................Develop computer models to ascertain the impact of co-firing of opportunity fuels on existing plants, showing the environmental and operational characteristics

High Temperature Materials / Corrosion-Resistant Materials

13*************......Advanced material development for 1600 ºF steam (corrosion resistance)
5*****........................Stronger corrosion resistant materials for advanced steam cycles - government labs/industry (in-situ)
5*****........................Materials development for 2000 ºF
*3***...........................Use newer high temperature materials as an upgrade in an existing plant, but use these at the existing unit's lower temperature levels. Since the high temperature material is used at lower-than-rated capability, use the resulting greater margin in material capability to improve corrosion resistance. A reasonable goal would be to double the life at under twice the cost.*
*3***...........................Pilot scale demo of ceramic heat exchanger by 2004*
*2**.............................High pressure 1300°F convective steam heater mid - term*
*2**.............................Low pressure 2200°F radiative air heater mid - term*
1...............................New Pulverized Coal Plants: High Temperature Materials needed near - term to 2006*

Greenhouse Gases and Climate Change

7*******....................Demonstrate CO_2 capture system by 2005
7*******....................Greenhouse Gas issues – mid - term to 2010
7*******....................Commercialize lower cost oxygen separation systems - near - term

6******......................Membrane oxygen/air separation technology
6******......................CO_2 , CO_2 to energy efficiency relationship, and greenhouse gases - near - term to 2006
6******......................Develop technologies supporting the increased use of biomass (for both existing and new units) to 10-20 percent fraction with coal
6******......................CO_2 Emissions issues – mid - to long - term
5*****........................Demonstrate CO_2 sequestration system by 2005
4****..........................Greenhouse Gas – long - term to 2015 and beyond
4****..........................Fundamental research on CO_2 sequestration
*3***............................Impacts from CO_2 sequestration- ocean, land (EOR), etc.-all options – near - term to 2006*
*3***............................Demonstrate CO_2 absorption in rock-mineralogical - near - term*
*3***............................Global Greenhouse Gas concerns, all greenhouse gases- mid - to long - term*
*2**.............................Improve basic greenhouse gas science (w/understanding) – mid - term to 2010*
*2**.............................Greenhouse Gas – Reduce, Capture, Sequester- mid - to long - term*
1...............................Existing Fleet: CO_2 extraction (separation) needed mid - term: 2006 - 2010*
1...............................New Pulverized Coal Plants: CO_2 sequestration needed long - term: 2010 - 2015 and beyond*
1...............................New Pulverized Coal Plants: Oxygen Enriched Combustion (CO_2 recycle) needed near - term to 2006*
1...............................Existing Fleet: Oxygen Enriched Combustion (CO_2 recycle) needed near - term to 2006*
1...............................Greenhouse gas technology need (CO_2) - near - term to 2006*
1...............................Greenhouse gas technology need- mid - term: 2006-2010*
1...............................Greenhouse gas technology need - long - term: 2010-2015 and beyond*
1...............................Existing Fleet: CO_2 separation needed long - term: 2010 - 2015 and beyond*
0.................................Sequestration (for both existing units and new units)
0.................................Capture (for both existing units and new units)
0.................................Low Net CO_2 Emissions (for both existing units and new units)
0.................................Improve Existing Fleet (for existing units only)
0.................................CO_2 Recycle with O_2 Combustion (for existing units only)

NOx Issues

11***********..........NOx-coupled with the issue that ammonia is not a good thing; would like to have in power plants/meeting NOx reductions without SCRs – near - term to 2006
7*******....................Develop low-temperature (about 300ºF) SCR catalyst to remove 90 percent of NOx by year 2003

6******.......................Remove 95 percent of NOx from combustion turbines by year 2003
5*****........................Develop materials/designs that allow 5-year life for waterwalls under low NOx burner conditions
5*****........................Continued topping combustor testing - near - term
5*****........................NOx reduction-make more cost effective – near - term to 2006
5*****........................SCR without ammonia – near - term to 2006
4****..........................NOx issues – near - to mid - term
4****..........................Integrated NOx control system demonstration - government/industry partnership - 2003
4****..........................Existing Fleet: Dry injection system needed - near - term to 2006
*3***............................Existing Fleet: Impact of Low NOx burners needed - near - term to 2006*
*3***............................Existing Fleet: Optimizing burners - smart control - needed near - term to 2006*
*3***............................Existing Fleet: Low temperature anti-NOx catalyst needed near - term to 2006*
*3***............................Existing Fleet: Low NOx burners for secondary NOx needed mid - term: 2006-2010*
*3***............................NOx-cost effectiveness and retrofit- near - term to 2006*
*3***............................Develop NOx control methods with a cost target of less than $500/ton NOx*
*3***............................NOx / Ozone (traces) - near - term to 2006*
*3***............................What is the Real Performance of SCR and SCR Catalysts with U.S. Coals? - near - to mid - term*
*2**..............................Existing Fleet: Alternative reductant gases needed near - term to 2006*
*2**..............................Existing Fleet: Natural gas reburning needed near - term to 2006*
*2**..............................New Pulverized Coal Plants: Oxygen Enriched Combustion (NOx control)*
*2**..............................Existing Fleet: Coal reburning needed near - term to 2006*
*2**..............................Existing Fleet: Ozone injection needed near - term to 2006*
*2**..............................NOx - SCR- near - term to 2006*
*2**..............................Interactions of NOx and Visibility; NOx - SCR- near - to mid - term*
*2**..............................Attain a NOx level of 0.1 lb / 10^6 Btu in existing units*
*2**..............................Burner development – near-term*
*2**..............................Integrated NOx / SOx removal - mid - term*
1................................Low NOx burners (for both existing units and new units)*
0..................................Collateral Damage from Using SCR- near- to mid - term
0..................................Cost/Availability of SCR- near- to mid - term
0..................................O_2 for NOx control (for both existing units and new units)

PM2.5 and Particulate Matter

6******......................Mercury issues - challenge of trying to find something that is affordable for mercury control – near - term to 2006

6******......................Regional haze (3***) vs. particulates (3***)- near - term

5*****........................PM2.5 issues – mid - term to 2010

5*****........................Continued testing of high temperature (1600ºF) particulate filter

*3***............................PM2.5 needs to be addressed mid - term: 2006-2010*

*3***............................Existing Fleet: Increase scrubber efficiency by mid - term: 2006-2010*

*3***............................Existing Fleet: Advanced baghouse materials needed mid - term: 2006-2010*

1................................Particulate PM2.5 concerns – near - term to 2006*

1................................SO_2, SO_4- near-term*

1................................Bagfilter materials that will collect multi-contaminants - mid - term*

Mercury, Hazardous Air Pollutants (HAPs), Toxic Release Inventory

5*****........................Regulatory Practical Limit toxic release inventory (TRI) needs - near - term to 2006

4****..........................Mercury issues (cost of control) - near - term to 2006

4****..........................Existing Fleet: Mercury scrubbing needed - near - term to 2006

4****..........................New Pulverized Coal Plants: Mercury scrubbing needed - near - term to 2006

*2**..............................Mercury control for low chlorine coals - 2005*

*2**..............................HAPs/Air Toxics (heavy metals) – mid - term to 2010*

1................................Global mercury issues – near - term to 2006*

1................................Mercury- near - term*

Waste Products

*2**..............................Waste Ash Utilization needed near - term*

0.................................Water Intake / Discharges needed near - term

0.................................Water Intake/Discharges

0.................................Total Maximum Daily Load (TMDL) – Water Issues needed near - term

0.................................Disposal of Ash and Solid Waste needed near - term

0.................................Land Use needed near - term

Appendix J Participant List by Name

Joseph S. Badin Energetics, Inc. 7164 Gateway Drive Columbia MD 21046 Phone:301/621-8432 Fax:301/621-3725 Email:jbadin@hotmail.com	David Bjorkbom Bechtel Group Inc. 8180 Greensboro Drive Suite 900 McLean VA 22102 Phone:703/748-9403 Fax:703/748-9444
Rita A. Bajura Federal Energy Technology Center U. S. Department of Energy 3610 Collins Ferry Road Morgantown WV 26505 Phone:304/285-4511 Fax:304/285-4292 Email:rita.bajura@fetc.doe.gov	Donald L. Bonk Federal Energy Technology Center U. S. Department of Energy 3610 Collins Ferry Road Morgantown WV 26505 Phone:304/285-4889 Fax:304/285-4469 Email:dbonk@fetc.doe.gov
Roderick Beittel D.B. Reilly Inc. 45 McKeon Road Worcester MA 01610 Phone:508/792-4811 Fax:508/792-4817 Email:rbeittel@dbriley.com	Arun C. Bose Federal Energy Technology Center 626 Cochrans Mill Road P. O. Box 10940 Pittsburgh PA 15236-0940 Phone:412/892-4467 Fax:412/892-4604 Email:bose@fetc.doe.gov
Ron K. Bhada New Mexico State University Department WERC P. O Box 30001 Las Cruces NM 88003 Phone:505/646-7697 Fax:505/646-4149 Email:rbhada@nmsu.edu	Thomas A. Burnett Tennessee Valley Authority 1101 Market Street MR 2T Chattanooga TN 37402 Phone:423/751-3938 Fax:423/751-2463 Email:taburnett@tva.gov

John W. Byam K&M Engineering & Consulting P. O. Box 366 Washington VA 22747-0366 Phone:540/675-1558 Fax: 540/675-1558 Email:jwbyam@earthlink.net	James T. Cobb University of Pittsburgh Department of Chemical & Petroleum Engineering 1137 Benedum Hall Pittsburgh PA 15261 Phone:412/624-7443 Fax:412/624-7449 Email:cobb@engrng.pitt.edu
Robert J. Copeland TDA Research 12345 West 52nd Avenue Wheat Ridge CO 80033-1917 Phone:303/940-2323 Fax:303/422-7763 Email:copeland@tda.com	Joseph N. Darguzas Sargent & Lundy 55 E. Monroe Street Chicago IL 60603-5780 Phone:312/269-6902 Fax:312/269-6169 Email:joseph.n.darguzas@slchicago.infonet.com
Michael R. DeLallo Parsons Infrastructure & Technology Group Inc. 2675 Morgantown Road Reading PA 19607 Phone:610/855-2675 Fax:610/855-2384 Email:michael.r.delallo@parsons.com	Nicholas J. Deluliis Consol Incorporated 4000 Brownsville Road Library PA 15129 Phone:412/854-6597 Fax:412/854-6613 Email:nickdeiuliis@consolcoal.com
Richard D. Doctor Argonne National Laboratory 9700 South Cass Avenue Argonne IL 60439-4815 Phone:630/252-5913 Fax:630/252-5210 Email:Rdoctor@anl.gov	Jan Friedrich Foster Wheeler Energy Corporation Perryville Corporate Park Dept. 171 Clinton NJ 08809-4000 Phone: 908/713-2242 Fax:908/713-2405 Email:jan_friedrich@fwc.com
Harvey N.Goldstein, P.E. Parsons Infrastructure & Technology Group Inc. 2675 Morgantown Road Reading PA 19607 Phone:610/855-3281 Fax:610/855-2384 Email:harvey.n.goldstein@parsons.com	Reginald Henry BENMOL Corporation 1121 King Street Alexandria VA 22314 Phone:703/683-4288 Fax:703/683-4635 Emailbenmol-rjh@erols.com

Connie Holmes National Mining Association 1130 17th Street NW Washington DC 20036 Phone:202/463-2654 Fax:202/833-9636 Email:cholmes@nma.org	John Hurley University of North Dakota/EERC P. O. Box 9018 Grand Forks ND 58202-9018 Phone:701/777-5159 Fax:701/777-5181 Email:jhurley@eerc.und.nodak.edu
Joseph Klosek Air Products & Chemicals Inc. 7201 Hamilton Boulevard Allentown PA 18195 Phone: 610/481-7871 Fax:610/481—2247 Email:klosekj@apci.com	Anthony E. Mayne Federal Energy Technology Center 626 Cochrans Mill Road P. O. Box 10940 Pittsburgh PA 15236-0940 Phone:412/892-4673 Fax:412/892-5917 Email:mayne@fetc.doe.gov
Dennis K. McDonald Babcock & Wilcox Company 20 South Van Buren Avenue Barberton OH 44203 Phone:330/860-6175 Fax: 330/860-2348 Email:mcdonald@pgg.mcdermott.com	Harvey M. Ness Federal Energy Technology Center 3610 Collins Ferry Road P. O. Box 880 Morgantown WV 26507-0880 Phone:304/285-4172 Fax:304/285-4403 Email:hness@fetc.doe.gov
Robin Oder EXPORTech Company Inc. P. O. Box 588 New Kensington PA 15068-0588 Phone:724/337-4415 Fax:724/337-4470 Email:magsep@sgi.net	Paul Pierre-Louis Illinois Dept. of Commerce & Community Affairs Office of Coal Development 100 West Randolph Street, Suite 3-400 Chicago IL 60601 Phone:312/814-3630 Fax:312/814-3891 Email:ppierrel@commerce.state.il.us
Sean Plasynski Federal Energy Technology Center 626 Cochrans Mill Road P. O. Box 10940 Pittsburgh PA 15236-0940 Phone:412/892-4867 Fax:412/892-5917 Email:plasynsk@fetc.doe.gov	Massood Ramezan Burns & Roe Services Corporation P. O. Box 18288 Pittstburgh PA 15236-0940 Phone:412/892-6451 Fax:12/892-4834 Email:ramezan@fetc.doe.gov

Fred L. Robson Kraft Work Systems Inc. P. O. Box 115 Amston CT 06231 Phone:860/610-7353 Fax:60/610-2151 Email:robsonfl@utrc.utc.com	Lawrence A. Ruth Federal Energy Technology Center 626 Cochrans Mill Road P. O. Box 10940 Pittsburgh PA 15236-0940 Phone:412/892-4461 Fax:412/892-4822 Email:ruth@fetc.doe.gov
David Schmalzer Argonne National Laboratory 955 L'Enfant Plaza North SW Suite 6000 Washington DC 20024 Phone:202/488-2415 Fax:202/488-2413 Email:schmalzer@anl.gov	Daniel J. Seery United Technologies Research Center 411 Silver Lane East Hartford CT 06108 Phone:860/610-7150 Fax:860/610-2151 Email:seerydi@utrc.utc.com
Edwin R. Simpson Transalta Energy Corp. 110-12th Avenue, SW Box 1900, Sta M Calgary, Alberta, Canada T2P 2M1 Phone:403/267-3640 Fax:403/267-3854 Email:ed_simpson@transalta.com	Edward Skolnik Energetics Inc. 501 School Street SW Suite 500 Washington DC 20024 Phone:202/479-2748 Fax: Email:
Jack Solomon Praxair Inc. 777 Old Saw Mill River Road Tarrytown NY 10591-6741 Phone:914/345-6442 Fax:914/345-6486 Email:jack_soloman@praxair.com	Joseph P. Strakey Federal Energy Technology Center 626 Cochrans Mill Road P. O. Box 10940 Pittsburgh PA 15236-0940 Phone:412/892-6124 Fax:412/892-4822 Email:strakey@fetc.doe.gov
Bill Sullivan PG&E Generating Company 7500 Old Georgetown Rd Bethesda MD 20814 Phone:301/280-6283 Fax:301/280-6917 Email:bsulliva@usgen.com	Mark Torpey Foster Wheeler Development Corp. 12 Peach Tree Hill Road Livingston NJ 07039 Phone:973/35-2232 Fax:973/535-2242 Email:mark_torpey@fwc.com

Peter Tortorelli Oak Ridge National Laboratory P. O. Box 2008 Oak Ridge TN 37831-6156 Phone:423-574-5119 Fax:423/574-0215 Email:tortorellipf@ornl.gov	Robert Von Hein ABB Power Plant Laboratories 2000 Day Hill Road Windsor CT 06095 Phone:860/285-4376 Fax:860/285-3861 Email:robert.j.vonhein@us.abb.com
Ken Warren Edmonton Power Capitol Square 10065 Jasper Avenue Edmonton, Alberta, Canada T5J 3B1 Phone:780/412-3506 Fax:780/412-3434 Email:kwarren@edpower.com	Richard E. Weinstein, P.E. Parsons Infrastructure & Technology Group Inc. 2675 Morgantown Road Reading PA 19607 Phone:610/855-2699 Fax:610/855-2384 Email:richard.e.weinstein@parsons.com
Ben C. Wiant Siemens Westinghouse Power Corp. 4400 Alafaya Trail MC 381 Orlando FL 32826-2399 Phone:407/281-2781 Fax:407/281-5014 Email:ben.wiant@swpc.siemens.com	Anthony J. Widenman DTE Energy 6100 W. Warren H-10A WSC Detroit MI 48210 Phone:313/897-1296 Fax:313/897-0940 Email:widenmana@dteenergy.com

Appendix K ORAL PRESENTATIONS

This information is not available on the Internet. Hard copies of overheads are contained in the bound volumes of the Proceedings. To request oral presentation hard copies, please contact Joan Barbish at (412) 386-4933, barbish@fetc.doe.gov.